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Supplier selection and purchase problem with fixed cost and constrained order quantities under stochastic demand ☆

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ABSTRACT

This paper addresses a supplier selection and purchase problem under stochastic demand. In particular, a buyer firm (manufacturer or retailer) wants to procure a product from a group of potential suppliers, which may quote different prices and have restriction on minimum and maximum order sizes, to satisfy the uncertain demand. In addition to holding and shortage costs, a fixed cost is incurred for the buyer when a potential supplier is selected. The objective is to select suppliers and to allocate the ordering quantity properly among the selected suppliers to minimize the total cost, including selection, purchase, holding and shortage costs. The problem is modeled as a Mixed Integer Programming (MIP). Properties of the problem are explored and a branch-bound algorithm is proposed for it. Also, a simple algorithm for the subproblem is proposed based on its special structure. Numerical experiments are conducted to evaluate the performance of the algorithm and some managerial insights are obtained.

1. Introduction

It is well known that competition among companies has become fiercer and fiercer and the marginal profit has been becoming thinner and thinner recently. In this situation, firms emphasize on reducing cost to increase their competence. Supplier selection and procurement are very effective ways to reduce costs because procurement management can not only save purchasing cost directly, but also reduce operating costs afterward (e.g. fault reduction, decrease in maintenance cost and others). Because of this, a lot of firms have been trying to manage their complete supply chains from upstream suppliers to the final end users of their products. As noted by Kraljic (1983): 'purchasing (an operating function) has evolved into supply management (a strategy one).' Supplier selection and ordering quantity allocation are important steps to supply management.

This paper addresses supplier selection and purchase problem with fixed selection cost and constrained order sizes under stochastic demand. This research is motivated by our experience on a real project, *Supplier Selection, Evaluation and Dynamic Management*, for a communication firm in China. At the end of each year, the managers of the firm need to make procurement budget and sign procurement contracts with its suppliers to satisfy the demand in the next year. They must decide which supplier is selected and how much to purchase from each supplier. However, the demand is uncertain when they make such decisions. In fact, procurement budget prevails and is an important decision for a firm. This research is to give a method for this problem.

Three steams of literature are related to this research: supplier selection and procurement, multi-supplier inventory and singe-period (newsvendor) inventory.

One way of supplier selection is to select a single supplier as the supply partner and to place all of the orders to this single supplier. Single sourcing can foster better collaboration and partnership and reduce cost. However, relying on single supplier will increase the risk of supply disruption and weaken the supply chain robustness. In order to overcome the shortcomings of single sourcing, many firms have adopted multiple sourcing, that is, they select multiple suppliers as partners and allocate their ordering quantities among these suppliers. This will cost a little more because selecting a potential supplier as a real one will incur a fixed cost (e.g., administration, negotiation, etc.) and the buyer firm should place at least a minimal order quantity to this supplier if one supplier is selected as a partner. As noted by McCutcheon and Stuart (2000) and Minner (2003), there are plenty of advantages and disadvantages attached with single or multiple suppliers. This paper addresses the supplier selection and purchase problem considering minimal ordering quantity and suppliers' limitation on capacity under stochastic demand. Whether single or multiple sourcing is adopted is determined by the demand and the suppliers' minimum and maximum order sizes.

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Supplier selection and purchase problem has absorbed a great deal of attention from industrial practice and academe. Rosenblat et al. (1998) developed an acquisition policy for supplier selection and purchase problem with multi-periods. Benton (1991) and Goossens et al. (2007) studied the supplier selection and purchase problem in which suppliers offer quantity discounts. Chauhan and Proth (2003) studied supplier selection and purchase problem with concave purchase cost and minimal and maximal ordering quantities and proposed heuristic methods for their models. These literatures assume deterministic demand. Awasthi et al. (2009) studied the supplier selection and purchase problem under stochastic demand with limitation on minimum and maximum order sizes and proposed a heuristic method for their model. They did not consider fixed selection cost. Burke et al. (2007) studied a purchase problem under stochastic demand with the set of selected suppliers and limitation on minimum order size and proposed an optimal approach for the model. They considered only the ordering quantity allocation problem. Anupindi and Akella (1993), Parlar and Wang (1993), Dada et al. (2007), Yang et al. (2007) studied supplier selection and purchase problem under random yield suppliers and uncertain demand. They did not consider the fixed cost and the restriction on minimum and maximum order sizes.

There are a lot of literatures on multiple supplier inventory management. Syam and Shetty (1996), Rosenblatt et al. (1998) considered the multiple supplier inventory problem with deterministic lead-time and demand. They modeled the problem as a Mixed Integer Programming and proposed algorithms to solve it. Vidal and Goetschalckx (1997) gave a review on this topic. Zhang (1996), Scheller-Wolf and Tayur (1999), Moinzadeh and Nahmias (1988), Chiang and Gutierrez (1998) considered the multiple supplier inventory problem under multiple periods, deterministic lead-time and random demand. They assumed two suppliers with different lead times, zero setup cost and characterized the optimal policy. Sculli and Wu (1981), Fong et al. (2000), Ramasesh et al. (1991) studied the multiple supplier inventory problems with stochastic lead-time. These researches used continuous review (s,Q) policy and determined the optimal number of suppliers, the reorder point, the total order quantity and its allocation among the suppliers. Minner (2003) gave an extensive review. Also, Bo van der Rhee et al. (2009) empirically studied how manufacturing managers/executives trade-off between cost, delivery, flexibility and service features in the supplier selection process for commodity raw materials, given acceptable quality.

Newsvendor problem is a very important model in inventory management and a basic building block of other complicated and advanced inventory management models. Moreover, newsvendor problem can be applied extensively in practice because of the reduction in product life cycle brought about by technological advance. Since 1950s, it has absorbed a great deal of attention from academe and many extensions have been developed. Eeckhoudt et al. (1995) extended the newsvendor problem to the case that the vendor is risk-averse (prudent). Jucker and Rosenblatt (1985) considered the newsvendor problem in which the supplier offered discount (all-unit or increment) based on the ordering quantity. Petruzzi and Dada (1999) and Khouja (1996) generalized the newsvendor problem with different vendor pricing policies and discounting structures. Henig and Gerchak (1990) and Ciarallo et al. (1994) extended newsvendor model to random yield. Nahmias and Schmidt (1984) studied multi-product newsvendor problem with capacity constraint. Bassok et al. (1999) considered multi-product newsvendor problem with substitution. Silver and Pyke (1998) and Khouja (1999) gave extensive reviews. However, they only studied the ordering quantity decision problem and none of them considered the supplier selection from a potential supplier set.

This paper addresses the supplier selection and purchase problem with fixed selection cost and limitation on minimum and maximum order sizes under stochastic demand. That is, a buyer (manufacturer or retailer) wants to select some from a set of potential suppliers as his partners. The suppliers' capacities are limited. If one supplier is selected, a fixed cost will be incurred and the order size to him is no less than a minimum order size. However, when the buyer makes the decision on supplier selection and purchase, the demand is uncertain. If he orders more than the realized demand, the excess stock incurs a holding cost. Once the ordering quantity is less than the realized demand, a penalty cost is incurred. The objective is to minimize the total cost including supplier selection, purchase, holding and penalty costs. We model this problem as a mixed integer programming and show that the problem is NP-complete. Some properties of the optimal solution to this problem are characterized and a branch-bound algorithm is proposed for it. Moreover, a simple algorithm is proposed for the subproblem based on its special structure. Numerical experiments are done to show the performance of the algorithm. Since our algorithm is an exact algorithm, some managerial insights can also be obtained based on the numerical experiments.

The remainder of the paper is arranged as follows. In Section 2, the basic mathematical model is formulated and some properties of the problem are proven. A branch and bound algorithm for the problem is proposed in Section 3. In Section 4, numerical experiments are presented to show the efficiency of the algorithm and some managerial insights are drawn. Some conclusions and further research topics are presented in Section 5.

2. The model

A buyer firm wants to procure a product from a set of potential suppliers to satisfy stochastic demand. We assume that all the suppliers in the identified set satisfy the buyer's qualitative criteria (quality, service, delivery, maintenance, etc.) and the final allocation will be based on the fixed selection cost and the price set by the suppliers. Define S as the set of n suppliers, indexed by i. For each supplier i, let K_i be the fixed selection cost and c_i be the price set by her. Supplier i has limited maximum capacity M_i and a restriction of the minimum order size m_i if the supplier is selected. The demand D faced by the buyer is a random variable following a known density function $f(\xi)$ and a cumulative distribution function $F(\xi)$. Let p be the selling price at the market, which is determined exogenously. If the buyer orders more than the realized demand, the excess stock incurs a holding cost, h, per unit. Once the buyer orders less than the realized demand, a penalty cost, s, will be incurred per unit. The buyer needs to decide the exact quantity to be ordered from each of supplier i in order to maximize the expected profit. Let x_i be the ordering quantity from supplier i and y_i be a binary variable. $y_i=1$ means that supplier i is selected and $y_i=0$ otherwise. Let

$$T(x_1,\ldots,x_n,y_1,\ldots,y_n)=Q(x_1+\cdots+x_n)-\sum_{i\in S}c_ix_i-\sum_{i\in S}K_iy_i$$

where

$$\begin{aligned}Q(x)&=pE(\min\{D,x\})-hE(x-D)^+-sE(D-x)^+\\&=(p+s)x-s\mu-(p+h+s)\int_0^x F(\xi)d\xi\end{aligned}$$

where $\mu=E(D)$ is the mean of the demand. $T(x_1,\ldots,x_n, y_1,\ldots,y_n)$ is the expected profit of the buyer. Then the supplier selection and purchase problem can be formulated as follows:

$$\begin{aligned}&\max T(x_1,\ldots,x_n,y_1,\ldots,y_n)\\&\quad\text{s.t.}\ m_iy_i\le x_i\le M_iy_i,\quad i\in S\\&\quad y_i\in\{0,1\},\quad i\in S\end{aligned}\tag{2.1}$$